RESEARCH BULLETIN 841 SEPTEMBER 1959

Harvesting and Drying of High Moisture Wheat

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CONTENTS

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ACKNOWLEDGMENTS

The writer wishes to express appreciation for the assistance of several groups: to H. T. Hurst B. J. Lamp, K. A. Harkness, C. A. Lamb, C. E. Bode, I. P. Blauser, C. K. Kline, J. E. Henry, W. L. Roller, and Phillip Rothrock for active participation on the project; to Edwin Nelson, Henry Faber, Dean Miller, John Clingerman, Harold Lezotte, Richard Frink, Robert Lichti, Richard Holdren, Robert Teale, Nejat Emirli, Shirish Pandya, and James Laub, student assistants; to Ohio Farm Electrification Council, International Harvester, Allis-Chalmers, Massey-Harris-Ferguson, John Deere, Ohio Farm Bureau, Behlen Manufacturing Company, and the Belt Corporation for the stimulus of the project, interest and financial support.

HARVESTING AND DRYING OF HIGH MOISTURE WHEAT

WILLIAM H. JOHNSON[2]

I. INTRODUCTION

Ohio has long grown and supplied soft red winter wheat. This wheat is usually lower in protein content than hard varieties and is used principally for pastry products. While the milling and baking characteristics of Ohio wheat have remained at high levels, farmers have been penalized when selling their wheat by having it down graded, due principally to low test weight and high moisture content.

In general the grade classification of wheat passing through Ohio's principle markets indicates that the grain does not grade as high as would be desirable (1). See Table 1. The shortcomings appear to be attributable to improper use of the combine in harvesting, humid harvest seasons, and inadequate drying or storage facilities.

There are problems with each method of harvest. The usual recommendation for combine harvest has been to start the machine only when the grain is below 14 percent. In the humid regions this delays the harvest season beyond actual grain maturity, and the work day is limited to the daylight afternoon hours. These two factors extend the harvest season. By delaying the harvest, the chances of lodged grain, high shatter loss, high cutterbar loss, and secondary weed growth become much greater. Grain, once dried to 14 percent, re-wetted and dried, reduces in test weight. This causes grade reduction and has been proposed as a possible contributing factor in the development of "sick" wheat (2).

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[1]Work was done under Project Hatch 82, Ohio Agricultural Experiment Station.

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Before actual work started, it was reasoned both from the standpoint of minimizing grain loss and preserving grade, that getting the grain out of the field at the earliest possible date would be advantageous. The combining of grain above 14 percent is one method by which this could be done in that the harvest season could be advanced and would also provide more harvesting hours. Drying of the grain would be essential in the humid areas.

TABLE 1.—Wheat by Grades Handled by Principal Markets in Ohio

Crop Year	No. 1	No. 2	No. 3	No. 4	No. 5	Sample Grade	Total	Tough*
1954—Cars	3,660	10,244	10,749	1,056	92	195	25,996	786
% of Total	14.1	39.4	41.3	4.1	.3	.8		
1953—Cars	16,395	9,609	1,070	100	30	67	27,271	242
% of Total	60.1	35.2	3.9	0.4	0.1	0.1		
1952—Cars	5,770	9,988	2,181	95	25	107	18,166	783
% of Total	31.8	55.0	12.0	0.5	0.1	0.6		
1951—Cars	219	4,568	5,503	369	95	645	11,399	5,826
% of Total	1.9	40.1	48.3	3.2	0.8	5.7		
1950—Cars	2,240	6,915	5,181	738	140	342	15,556	4,613
% of Total	14.4	44.5	33.3	4.7	0.9	2.2		
1949—Cars	144	4,805	8,536	4,556	282	400	18,723	2,548
% of Total	0.8	25.7	45.6	24.3	1.5	2.1		
1948—Cars	1,384	4,285	7,534	5,331	444	268	19,246	4,621
% of Total	7.2	22.3	39.1	27.7	2.3	1.4		
1947—Cars	450	5,283	5,957	1,899	1,032	1,325	15,946	4,194
% of Total	2.8	33.1	37.4	11.9	6.5	8.3		
1946—Cars	2,647	7,944	2,162	228	31	168	13,180	1,436
% of Total	20.1	60.3	16.4	1.7	0.2	1.3		
1945—Cars	781	7,830	6,125	312	41	231	15,320	2,074
% of Total	5.1	51.1	40.0	2.0	0.3	1.5		
1944—Cars	3,478	5,685	506	69	19	74	9,831	80
% of Total	35.4	57.8	5.1	0.7	0.2	0.8		
1943—Cars	22	190	1,483	1,588	989	342	4,614	1,855
% of Total	0.5	4.1	32.2	34.4	21.4	7.4		
1943-1954—Cars	37,190	77,346	56,987	16,341	3,220	4,164	195,248	29,058
% of Total	19.0	39.6	29.2	8.4	1.6	2.1		14.9

*Tough wheat is not a grade designation in itself, but a qualifying condition on the grade if the moisture of the grain is in the range of 14-15.5 percent. Example: U. S. No. 2, Tough.

II. OBJECTIVES OF THE STUDY

Specifically, this study was established to:

(1) Determine harvesting and drying methods by which the condition of Ohio wheat can best be preserved.

(2) To determine the effect of grain moisture content and stage of harvest on resulting grain loss, and over-all combine functioning.

(3) To determine the capability of various drying methods to preserve grain condition.

III. METHOD OF STUDY

This study has been in progress five years. Two soft-red winter wheat varieties have been used, Seneca and Butler. Since the major work has been done with Seneca, only this variety will be reported in detail.

A great deal of emphasis was placed on the combine since it is the most common means of harvest at the present time. However, it is hoped that the information gained will permit ready evaluation of other methods of harvest.

(A) Potential Grain Condition and Quality

The term "grain condition" as used here is to denote the physical condition of the grain. It is characterized by test weight, 1,000 kernel weight, germination and moisture content. Quality is used to denote the actual milling and baking characteristics of the grain as measured by standard tests.

In order to measure the results of the project, a study was made to determine the grain condition and quality typical of the field at each stage of harvest. This provided a basis to which the grain from any treatment could be compared. This will be referred to as the potential condition and quality of the grain.

Two methods were used to obtain the potential condition samples. Samples were cut from the standing grain from random areas of the field. A bundle of grain from each area was divided and two samples accumulated. One was threshed immediately, the other was stored inside and threshed dry. Samples were taken once or twice daily throughout the normal harvest season. Thereafter, samples were taken about twice weekly.

(B) The Field Harvest

Combine efficiency tests were run at various moisture contents between 28 and 12 percent grain moisture, both as the grain was originally drying in maturation and in the re-wetting and re-drying phase. In this evaluation, date of harvest was variable also. The determination of combine efficiency followed the system developed by McCuen and Silver (3). An area of 1/100 acre was established in the field. The combine was loaded ahead of the test plot. Samples of grain, chaff, and straw were collected from the combine in the test area. See Figure 1. The grain from the straw and chaff samples was reseparated and rethreshed to obtain the grain losses. See Figure 2.

The cutterbar loss determination involved two evaluations: Amount of grain on the ground ahead of the combine from random areas selected over the field, deducted from the amount of grain picked up from five 1/10,000 acre random areas within each combine test plot. See Figure 3. These tests yielded information on cylinder, rack, shoe, and cutterbar losses.

Shatter loss proved to be most satisfactorily evaluated by placing screen trays between the rows at random locations over the field. Daily checks were made on these trays. Even so, birds or insects hampered the evaluation.

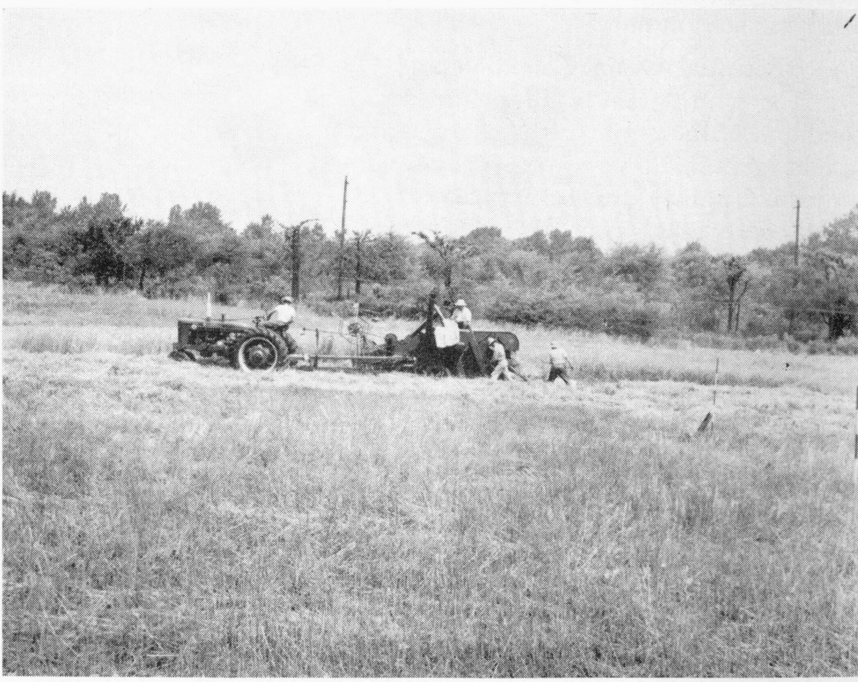

Figure 1—Collection of samples from the combine for the determination of machine losses.

The grain samples which resulted from the field tests were weighed, sampled for moisture, rapidly dried with forced air, then saved for grain condition determinations.

It was difficult under test conditions to total the various losses and grain tank yield to determine a theoretical yield. This is true because of the difficulty of evaluating shatter loss and because bird or wildlife damage could not be evaluated. It seemed important to evaluate the amount of grain harvested as influenced by date or moisture content at harvest as well as variation in harvest method. In order to do this an experiment was designed which replicated several treatments. Within each of those plots the grain tank yield, machine loss, shatter loss, was determined. Each plot contained approximately 1/3 acre and was harvested with a combine.

Six different combines were used in the tests. Not all were studied in detail; however all were used in high moisture grain. Forward travel rate and cylinder-concave clearance were the machine variables. Cylinder speed in general was constant at 1400 RPM for the 15-inch diameter full width cylinders. Length of straw threshed was held constant at about 24 inches.

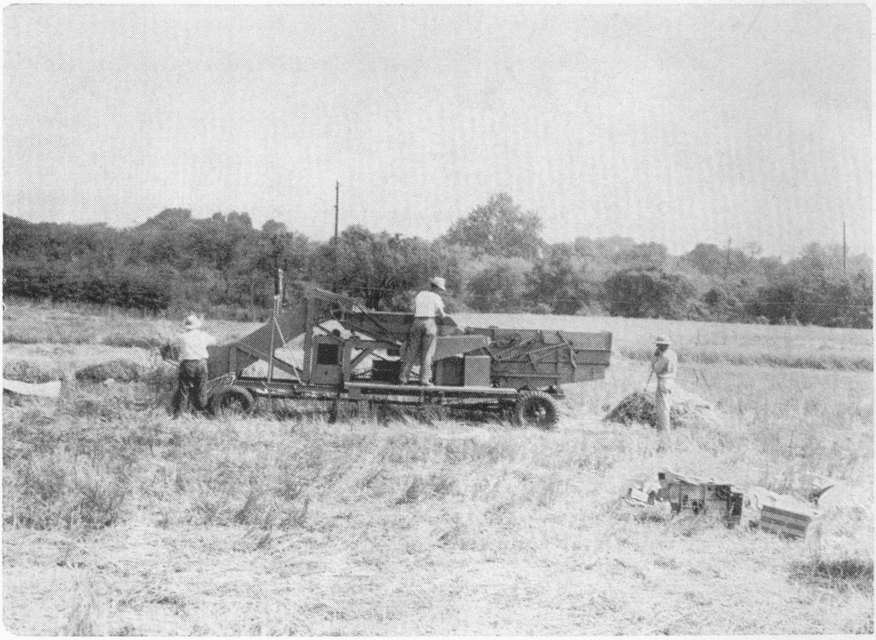

Figure 2—Rethreshing samples collected behind the combine to determine machine losses.

Figure 3—Grain which was lost by the cutterbar was evaluated by picking up kernels from a small area.

A windrower was used two years and a mower-buncher was tried one year as a means of windrowing. The windrow was used in an attempt to increase the drying rate of the grain. Both cutterbar loss of the windrower and combine pick-up loss were evaluated. A conventional cylinder pick-up attachment was used one year, pick-up guards on a conventional cutterbar the second year.

(C) The Drying Phase

Bulk harvest of grain was made at various grain moisture contents between 28 and 13 percent. Grain which was re-wet by rain as well as grain which was drying as a result of maturation was dried. Most of the grain was dried in small 3.5 bushel bins; however some 80 bushel bins were also used. See Figures 4 and 5. The depth of grain was normally 30 inches except where it was necessary to decrease the depth to obtain the higher air flow. Three drying temperatures were used: natural air, heated air at 100° F. and 150° F. Air flows were varied from about 30 cfm per bushel to 2.5 cfm per bushel.

The drying equipment consisted of a high pressure blower, electric heater, and small bins. Air was throttled from the central plenum chamber to each bin. Although this provided a simple arrangement for drying, several limitations were experienced. About eight inches of static pressure was carried in the central plenum chamber. In order to obtain low air flows, almost complete throttling between the plenum chamber and bin was required. Where small air leaks existed between the bin and plenum chamber, adequate control of the air was not obtained. As additional bins of grain were added in the drying process, readjustment of the system was required. That is, the static pressure of the plenum chamber was corrected after more bins were added. Adjustment of any one bin affected the whole system.

Electric strip heaters were used. The air to the bins was thermostatically controlled at 100° F. No attempt was made to control the temperature of the natural air bins.

Figure 4—Equipment used to dry 18–3.5 bushel bins. The high pressure fan and electric heat source are shown.

Air flows were measured with a vane type anemometer. The air flow from 1 sq. ft. of the surface of the bin was restricted at a ratio of 20 to 1 in order to use the anemometer. This air flow device was calibrated with a standard gas flow meter which is used to calibrate natural gas meters.[3] There is some error remaining in this system since it was not possible to fully determine the change in air flow from the bin with or without the air flow meter. It was possible to duplicate readings from the bins. It is assumed that the air flow readings are within 10 percent of the true value.

The bins were dried until the top layer of grain was 14 percent. At this time samples of grain were removed from the top and bottom of the bin. (In some cases only a composite sample of the bin was taken.) Moisture content was immediately determined on these samples and they were later subjected to various tests: Weight per bushel, 1000

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[3]Calibration made by the Ohio Fuel Gas Company, Columbus, Ohio.

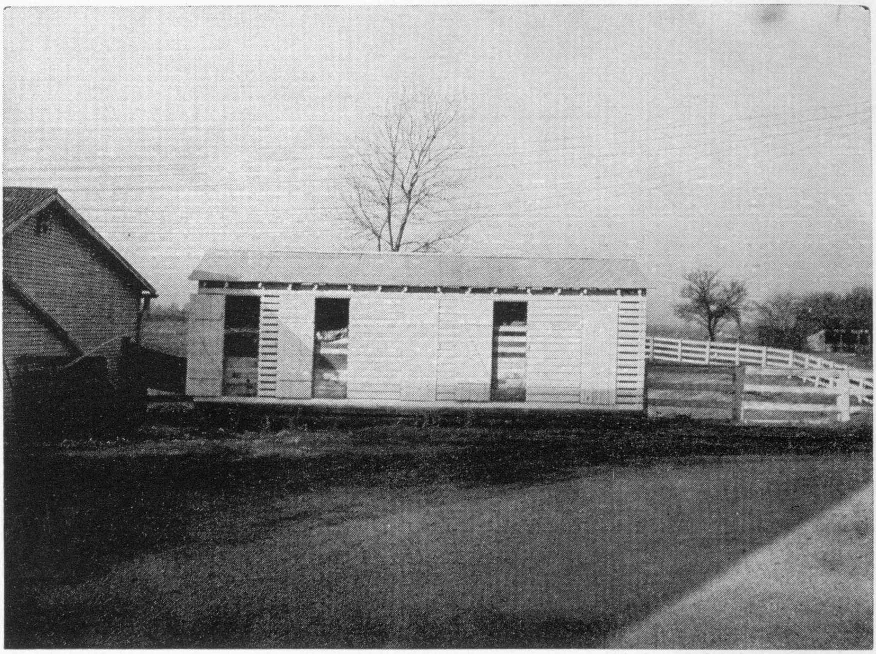

Figure 5—Five 80 bushel bins were used to dry the grain with forced unheated air.

kernel weight, germination,[4] split kernels, dockage and visual grade inspection.[5] In some cases milling and baking tests were also made.[6]

Throughout drying, the incoming air temperature both wet and dry bulb, outgoing dry bulb temperature, and airflows were observed.

(D) **Miscellaneous Determinations**

There were other phases of this study which provided supplemental information.

Grain moisture contents were observed in the field. The effect of dews, rains, and windrowing on the grain and straw moisture relationships were observed.

A series of laboratory tests were conducted to determine the effect of different variables at the cylinder on kernel damage. See Figure 6. It will be shown later that both kernel damage and the threshing loss was quite high when threshing high moisture grain. The ideal action would be one that would be severe enough to remove the grain yet cause a minimum of damage to the kernel. The variables studied were: A steel rasp cylinder, rubber covered flail bar cylinder, steel or rubber covered concave bar, grated or solid concave, cylinder speed and cylinder-concave clearance.

Samples of standing grain were cut from the field and immediately threshed in small laboratory cylinders. The amount of unthreshed grain was evaluated by rethreshing and the resulting grain sample was evaluated by means of test weight, germination, and visual damage.

An analysis of weather during July was made. Hourly rainfall and relative humidity records were obtained for Columbus, Ohio, for the period of 1942-56 inclusive (4). On the basis of these data each day was categorized according to the following: Grain could be combined at or below 14 percent, grain could definitely not be combined at or below 14 percent, and a questionable category but grain likely could be combined at 20 percent or below. The decision on each day was somewhat arbitrary; however, the following criteria was used as a guide:

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[4]Germination tests were conducted by the Agricultural Laboratory, Ohio Department of Agriculture, Reynoldsburg, Ohio.

[5]Mr. Philip Rothrock, Columbus, Ohio, retired federal grain inspector supervised the grading.

[6]Milling and baking tests were made at the Soft Wheat Quality Laboratory, Ohio Agricultural Experiment Station, Wooster, Ohio, Mr. C. E. Bode in charge.

1. Combinable at 14 percent—No rain for the day before 8:00 p. m., relative humidities below 55 percent for the afternoon, no rain greater than 1/4" during the preceding 24 hours.

2. Not combinable—More than a trace of rain during the afternoon, more than 1/2" of rain during the preceding 24 hours. Relative humidities above 65 percent for the afternoon.

3. Questionable but likely combinable at 20 percent—An intermediate condition of the above.

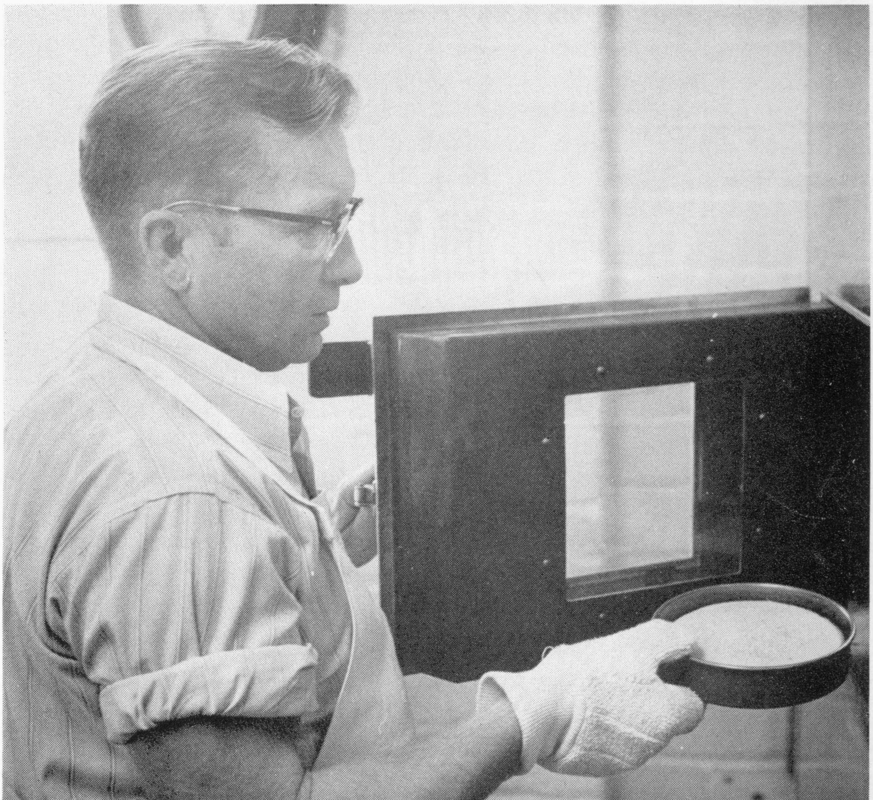

Figure 6—Baking tests conducted in the laboratory are a final evaluation of the wheat crop.

These data were compiled to show the number of days on which the combine could function at 20 percent grain moisture as well as at 14 percent for the period of July 5-15. Recurrence intervals were estimated by the method proposed by Gumbel for the longest consecutive number of combinable days at 14 percent between July 1 and 25, and the total number of combinable days between July 5 and 15, at 14 percent and 20 percent (5).

(E) **General**

All weights taken in the field were corrected to 13½ percent moisture before compilation.

Where condition or quality determinations were made on samples the grain was conditioned until it was within the range of 12-13½ percent before determinations were made.

IV. SIGNIFICANCE OF CONDITION AND QUALITY MEASURES

Since a great deal of emphasis has been placed on the condition and quality of the grain in this study, it seems well to elaborate on the significance of some of these measurements.

(A) TEST WEIGHT

Test weight is a weight per unit volume, measured in pounds per bushel, which is one factor considered by buyers in determining the price offered for wheat. A reduction in test weight is not extremely significant in reducing the market price of grain. See Table 2. Also millers use test weight as an indication of flour yield.

(B) MOISTURE CONTENT

Originally discounts were established on the price offered for high moisture wheat in an effort to discourage the movement of such grain onto the market. Recently, however, drying facilities have increased

TABLE 2.—The Relationship of Test Weight and Price Discounts

Pounds per Bushel	Cents per Bushel Discount
60 or over	1¢ premium
58–60	none
56	3
55	6
54	9

both on the farm and at the elevator level. This makes possible the conditioning of high moisture grain and greatly enhances the potentialities of high moisture wheat harvest as a practical method of harvest.

(C) GERMINATION

Germination is of special interest to the seed producer. It can also be regarded as a measure of the stability of grain in storage. A dead kernel is more likely to spoil than a viable kernel.

(D) 1000 KERNEL WEIGHT

The 1000 kernel weight is relative to dry weight per kernel. Any bacterial action, mold growth, or leaching will be reflected in a lower weight per kernel. This evaluation is also relative to the number of pounds of dry matter harvested per acre.

(E) MILLING AND BAKING

These evaluations evaluate the actual quality of the grain in terms of a final product. At the present time these determinations are not directly reflected in market price. In the long term market conditions, milling and baking quality is reflected in that buyers chose grain from areas that are known to produce satisfactory grain.

V. CERTAIN HARVEST CHARACTERISTICS OF SOFT RED WINTER WHEAT

In the presentation of data the five years have been combined where applicable. In many cases a range of values is given. This denotes the amount of variability noted for the years studied. This method seems more desirable than presenting single values. Results are drawn from the potential condition samples.

The rate of drying of the grain for this period appears to be about 2.5 percent per day. See Figure 7. There would normally be about four days between 20 percent and 14 percent. One year during the study there was 16 days.

A delay of the grain harvest will result in considerable loss in test weight and the period of highest test weight is relatively short. See Figure 8. The rate of test weight loss appears to be about .23 pounds per bushel per day. These data are proposed to show the instability of the potential test weight of standing grain.

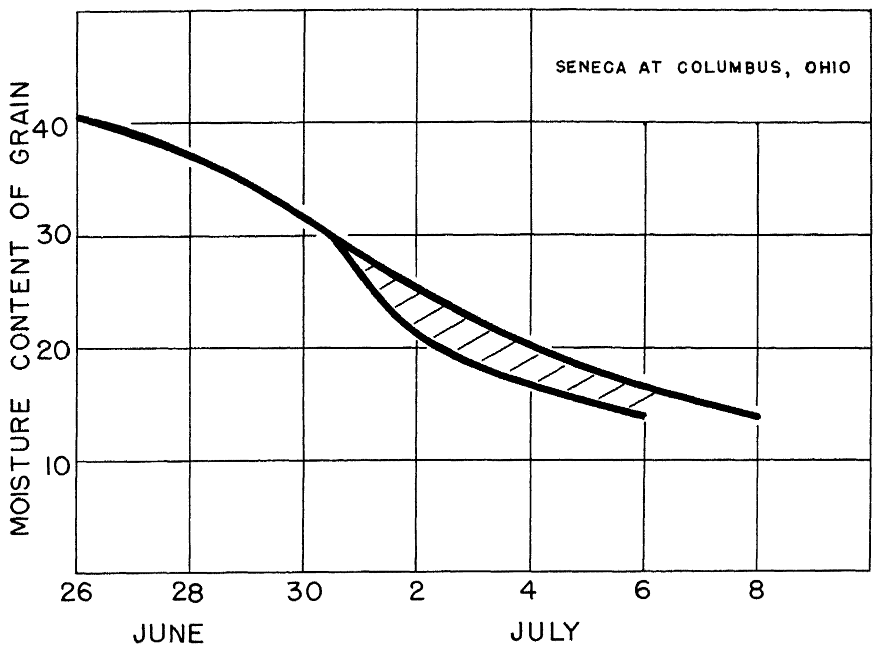

Figure 7

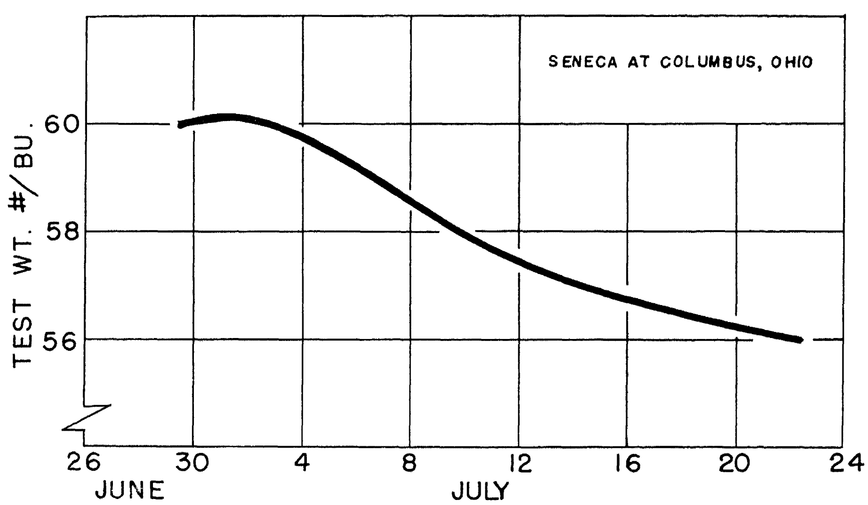

Figure 8

Germination drops only slightly as grain stands in the field. See Figure 9. It is doubtful if the drop as shown has much practical significance.

The reason for test weight reduction as the grain is exposed in the field caused much concern. There were two possibilities for the cause: (1) with each re-wetting the grain does not re-dry to its original volume, or (2) dry matter is leached or oxidized as the grain is subjected to weathering. In order to check this, 1000 kernel weights were observed as influenced by time.

The dry matter per acre does apparently reduce somewhat; however in 20 days the reduction is only in the order of 1.4 percent, whereas the drop in test weight for the same period is in the order of 6.5 percent. See Figure 9. From this it would appear that dry matter loss contributes very little to the test weight reduction. Apparently the kernel increases in volume as the harvest is delayed.

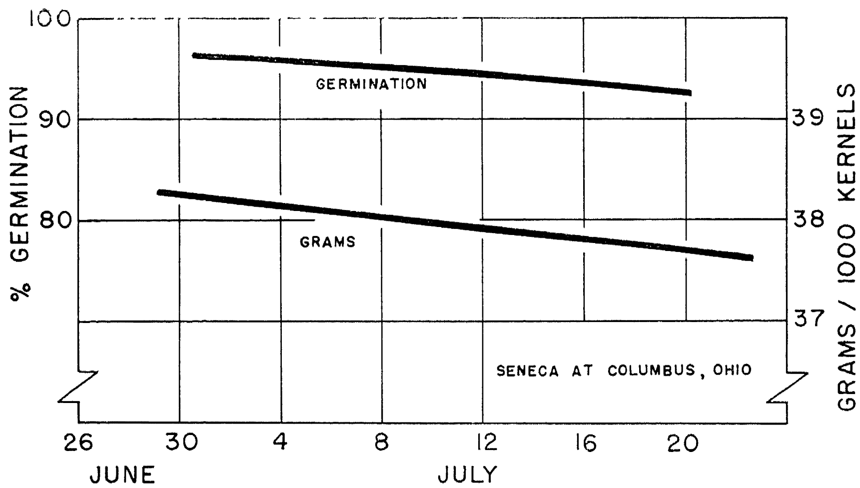

Figure 9

Evaluations were made to determine the effect of delayed harvest on quality. The results of a series of milling and baking tests will be summarized here, only slight differences were detected. See Table 3.

(1) Break flour yield increased with time of exposure. High break flour yields are an indication of greater quantities of fine flour produced at the head end of the experimental milling process (6).

TABLE 3.—Results of Milling and Baking Tests on the Potential Condition and Quality Wheat Samples*

Date	Break Flour Yield %	Pearl-ing Index %	Particle Size Index %	Flour Yield %	Mixogram Area Sq. Cm.	Cookie Diameter Cm. × 2	Protein	
							Wheat	Flour
June 29	22.7	47.4	16.7	68.5	72	17.9	10.7	9.4
June 30	25.7	45.5	20.0	67.9	69	18.0	9.1	7.9
July 1	23.1	44.9	19.4	68.1	71	17 7	9.9	8.6
July 3	24.1	45.3	16.8	67.7	69	17.6	10.0	8.7
July 8	24.6	49.3	20.8	69.9	70	17.7	10.0	8.8
July 24	31.0	58.8	27.7	67.5	68	18.0	10.4	9.1
LSD	2.1	1.1	2.5	2.5	3.7	.3	----	--

*From samples field cut, stored and threshed dry, 1953.

(2) Pearling index increased with time of exposure. The greater the pearling index, the softer the kernel texture (6).

(3) Particle size index increased for the same three week period of exposure. The higher the particle size index the finer was the resulting granulation (6).

There was essentially no difference between samples for the remaining evaluations. The major difference associated with extended exposure of the grain to weather is to soften the kernel. Quality for baking seemed unchanged. In general, this means that as long as grain is handled well during and after harvest the time grain stands in the field does not significantly alter the quality.

VI. WEATHER CHARACTERISTICS OF THE HARVEST SEASON

From the summary of weather data the following statements can be made concerning the combine season for Columbus, Ohio.

(1) For the period of July 5-15, 1942-56, there were 4.5 days per year when wheat could be combined at 14 percent; 7.7 days per year when wheat could be combined below 20 percent.

(2) Every year it is expected that the total number of combinable days between July 5-15 would be greater than 1 when grain is combined at 14 percent, 4 at 20 percent. The same probability statement can be made for 2 years, 4 at 14 percent, 7 at 20 percent; for 10 years 7 at 14 percent, 10 at 20 percent.

(3) Every year it is expected that the longest consecutive number of combinable days between July 1 and 25 would be at least 2 days in length. Every 2 years at least 5 days in length, and every 20 years at least 10 days in length.

(4) The length of a weather cycle, that is the center of a rainy period to the center of the next, appears to be about 10 days as evaluated by a moving average.

VII. THE EFFECT ON THE GRAIN OF THRESHING AT HIGH MOISTURE

From the data presented, wheat should be harvested as early as July 1 when the grain moisture content is about 27 percent. However, by immediately threshing and drying the wet grain the potential test weights as observed by the cutting and dry threshing method were not obtained. See Figure 10. The deviation of the two curves around July 8 marks a period of rain which increased the moisture content of the grain.

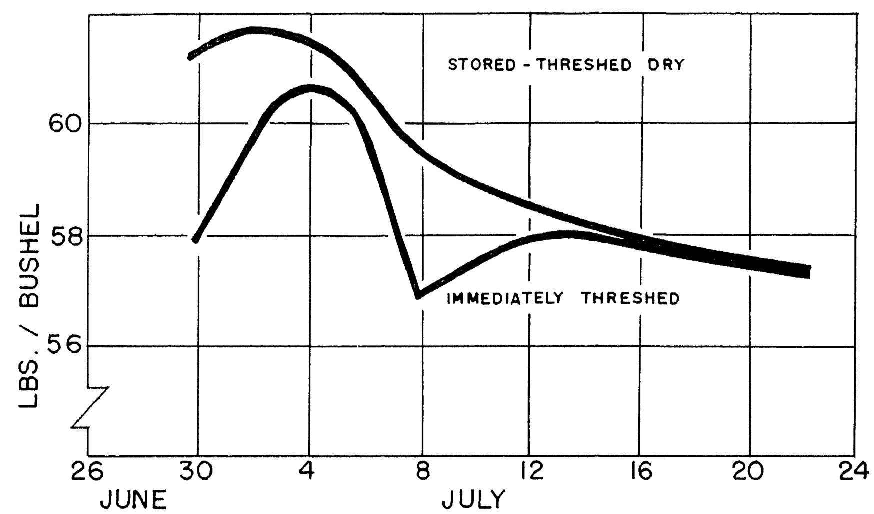

Figure 10

The same data are illustrated in Figure 11 except it is only the precombine portion of harvest. Similar data taken by Berg, Ottosson, and Aberg corroborates the data of this study (7). See Figure 12. An attempt was made to generalize all this work. See Figure 13. A range

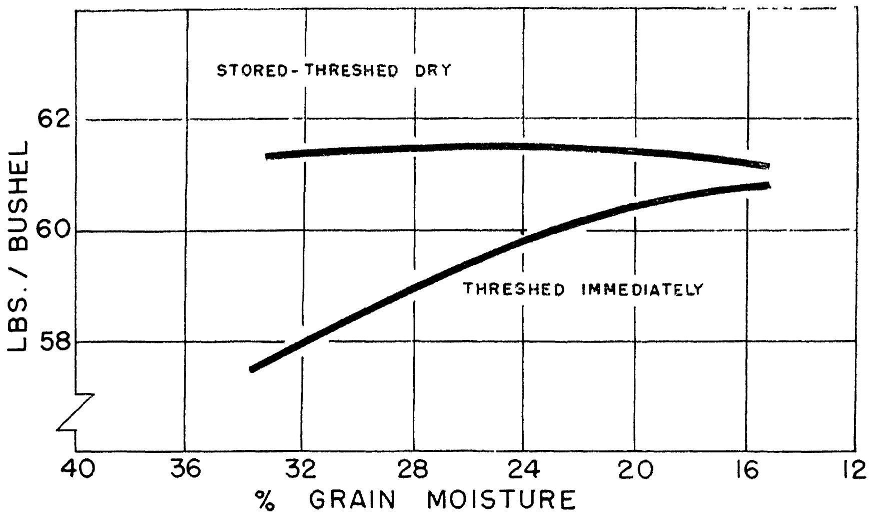

Figure 11

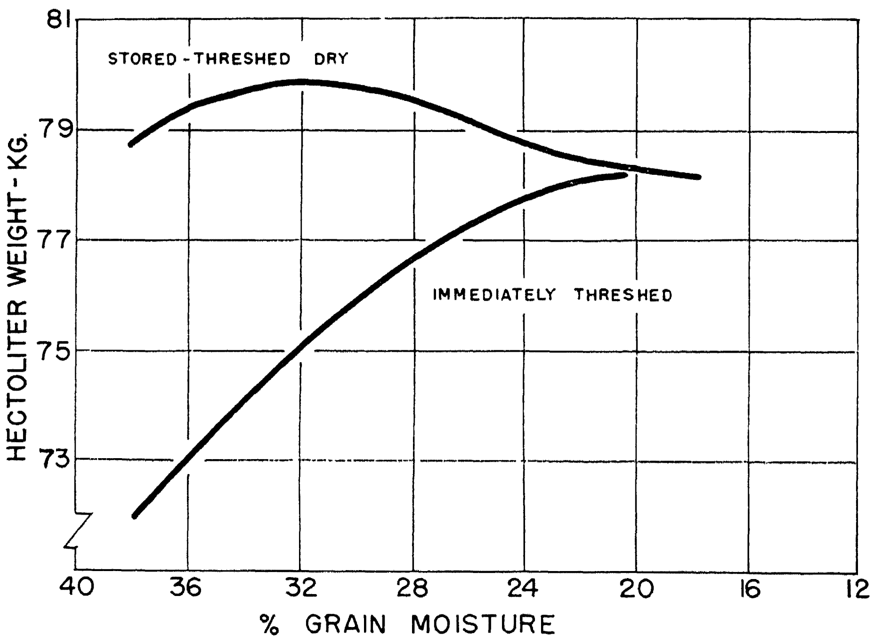

Figure 12

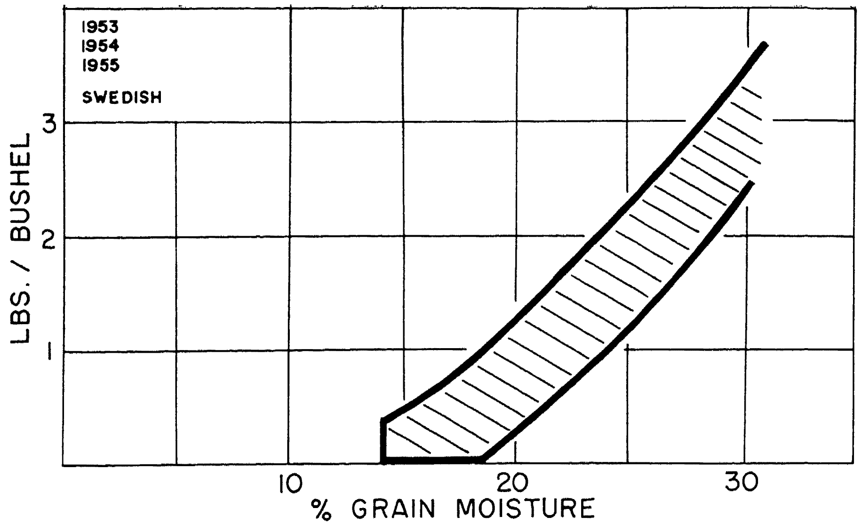

Figure 13

of the reduction in test weight is proposed because cylinder speed, cylinder-concave clearance and cylinder type will influence the test weight reduction at any moisture content.

Germination is also affected by the high moisture harvest. See Figure 14. This also is an attempt to generalize with the same qualifying variables to justify the proposed range of values.

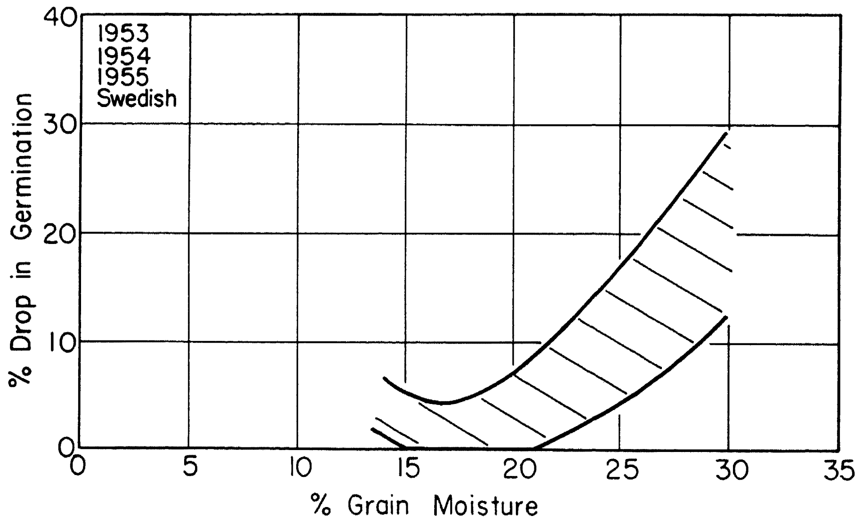

Figure 14

It seemed imperative that the cause of the drop in condition of the immediately threshed wet grain be established. The cause seemed to be between kernel damage which increased the volume of the kernel or additional dry matter accumulation below 30 percent grain moisture.

The test weight determination is a volume-weight determination whereas the 1000 kernel weight is related to a weight per kernel. If the drop in test weight is to be attributed to a reduction in dry matter the 1000 kernel weight should also be reduced. If such is not the case, that is the dry matter be constant, something must cause an increase in volume of the grain.

Test weights and 1000 kernel weights were taken for the potential condition and bin samples. A statistical correlation between test weight and 1000 kernel weight failed to show significance, r = .05 whereas r 5% = .298 for 44 samples.[7] The reduction in test weight must be attributed to something which increases the volume of the kernel.

Upon further examination of the samples threshed at high moisture, split kernels were found. The seed coat of these kernels was intact on one side of the kernel which would increase the volume of the kernel. See Figure 15. The number of split kernels is presented in Table 4.

From these data it appears that kernel damage would account for the drop in test weight. No attempt has been made to relate the amount of split kernels to a quantitive reduction in test weight.

The decrease in the germination of the wet threshed grain could also be explained on the basis of kernel damage.

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[7]Here, r means correlation coefficient. For statistical significance r must be greater than r 5 percent.

TABLE 4.—Split Kernels Found in Samples Harvested at Various Moisture Contents

% Grain Moisture as Threshed	% of Kernels Split by Weight
33.4	10.3
29.4	7.3
23.4	2.7
20.3	1.0
18.4	1.0
15.8	0

Figure 15—Visual evidence of damaged kernels threshed above 20 percent grain moisture.

It would appear, from the standpoint of minimizing kernel damage that threshing must be limited to moisture contents below 20 percent unless other principles of threshing, better adjustment, or modifications of the present cylinder could be obtained. Tests were conducted to determine the effect of cylinder design and adjustment (8). See Tables 5 and 6.

When considering the effects of cylinder-concave design there was no significant difference among the six combinations of variables studies. See Table 5. When testing grated versus solid concaves, the grated concave gave significantly higher test weight and lower damage. While germination was lower for the solid concave it was not significant. It was also apparent from the detailed data that rubber on either the cylinder or concave was undesirable at the 24.7 percent moisture level. At moisture contents below 20 percent there seemed to be little difference between rubber or steel surfaces.

TABLE 5.—The Effect of Cylinder-Concave Design on the Resulting Condition of Wheat

Cylinder Type	Rasp	Rasp	Rasp	Flail	Flail	Flail
Concave Type	Grated	Grated	Solid	Grated	Grated	Solid
Concave Surface	Steel	Rubber	Steel	Steel	Rubber	Steel
7 day germination percent normal	89.6	88 3	77.7	85.6	87.0	81.6
Visual damage percent	1.48	1.20	1 90	1 0	1.5	1.8
Test weight pounds per bushel	58.3	58.4	58.0	58.0	58.2	57.7

Tests were made at 1260 RPM cylinder speed, ¼" cylinder-concave clearance, at moistures of 24.7, 19.6, 16 3 and 13 percent. More detailed data available.

The effect of cylinder adjustment was also determined. See Table 6. Some adjustments in this series of tests were quite extreme as demanded by such a study. Grain condition improved slightly with decreased cylinder speed. Optimum cylinder-concave clearance was ¼ inch. Both close and wide cylinder-concave clearances, ⅛ and ⅜ inch indicates damage to the grain condition. The cylinder used was fed nearly on the concave tangent which resulted in somewhat erratic feeding at the wide cylinder-concave clearance. This could account for the damage resulting at ⅜ inch.

It seems that neither cylinder design or adjustment as studied here can minimize damage of threshing wheat above 20 percent. Grated concaves, low cylinder speed and relatively wide cylinder-concave clearances help, but will not eliminate damage.

TABLE 6.—The Effect of Cylinder Adjustment on the Resulting Condition of Wheat

	Grain Moisture, %				Cylinder Speed			Cylinder—Concave Clearance, inches		
	24.7	19.6	16.3	13.0	1140	1260	1400	⅛	¼	⅜
7 day germination % Normal	79.4	91.9	92.1	87.8	89.3	88.4	85.8	85.5	89.3	88.2
Visual damage %	1.27	.55	.65	1.88	.69	1.15	1.52	1.23	.98	1.16
Test weight lbs /Bu.	57.0	58.5	58.2	58.3	58.1	58.2	57.8	57.9	58.1	58.0

Tests were made with the 15" rasp cylinder, grated steel concave. More detailed data are available.

VIII. METHOD AND COMBINE EFFICIENCY

The combine was evaluated in two ways: (1) When considering the combine season how much of the yield can the combine harvest, and (2) What is the efficiency of the machine at various stages of the harvest season in handling what it receives?

(A) YIELD AS INFLUENCED BY DATE OF HARVEST

The amount of grain the combine can harvest decreases with time. See Figure 16. This figure also represents a grain balance which accounts for the various field losses. With each day of delay, after 30 percent grain moisture, there is 12 pounds per acre less grain that the combine can harvest.

The determination of the combine efficiency at various stages of harvest is somewhat more involved. The harvest season has been divided into two distinct periods: (1) The original drying period, is characterized by the fact the crop is losing moisture in maturation until the grain is at 14 percent for the first time. (2) The re-wetting and drying period, is that condition after the grain has dried and come into equilibrium with the prevailing climatic conditions.

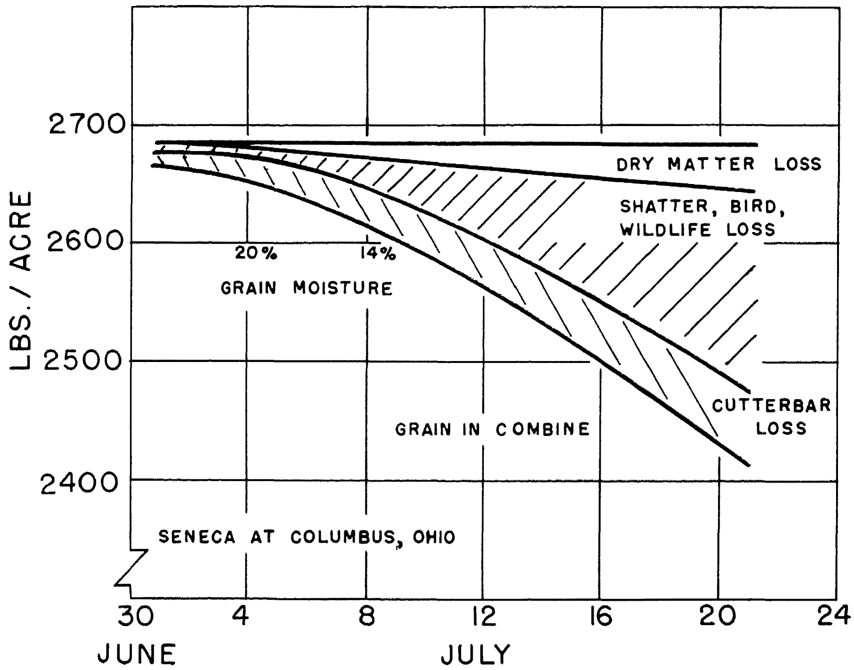

Figure 16

(B) COMBINE EFFICIENCY

Combine losses are shown as the condition of the crop changed. During the original drying period of harvest, grain moisture content was used as a means of characterizing the crop condition. Most of the combine tests were run in the afternoon, at which time for the original drying period there is a fair relationship between grain and straw moisture. See Figure 17. In a fundamental sense straw moisture appeared to be the variable governing grain loss; however since there is a relationship between straw moisture and grain moisture for this period grain moisture can be used. Grain moisture is more commonly understood and simpler to use.

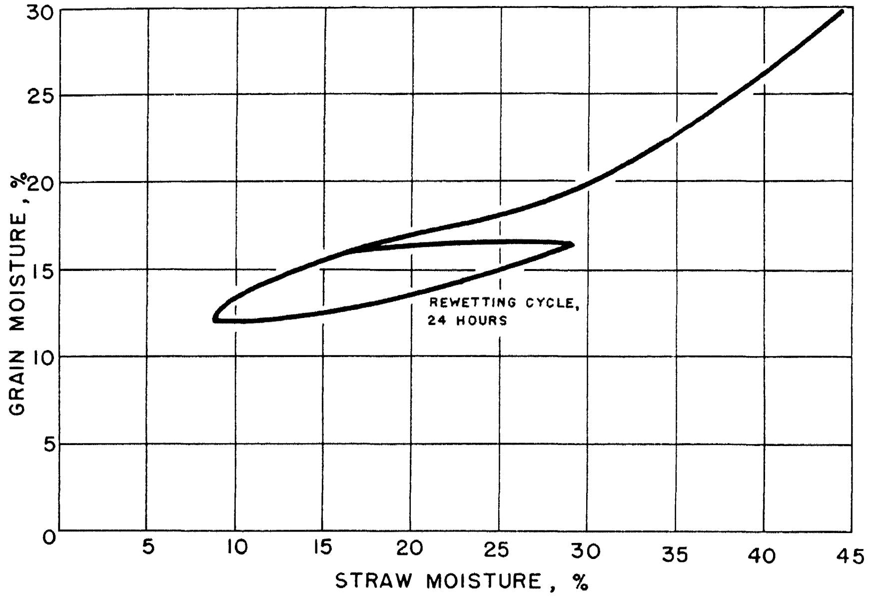

Figure 17

In the re-wetting and drying period, grain moisture was not adequate to denote the condition of the crop because there is no definite relationship between grain and straw moisture. See Figure 17 and 18. Since straw moisture more nearly governs the grain loss, it was used during this period to denote the condition of the crop.

The results are proposed in a range of values. Seasonal differences are quite extreme even though similar varieties and machines were used.

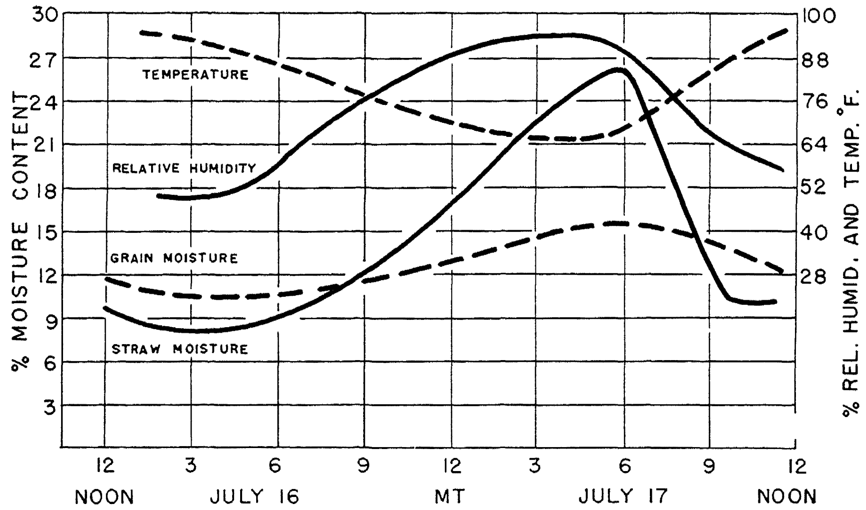

Figure 18

Cylinder Loss

An increase in moisture content at the time of combining, results in more unthreshed grain for any one cylinder-concave clearance or cylinder speed. See Figures 19 and 20. It seems just as evident that

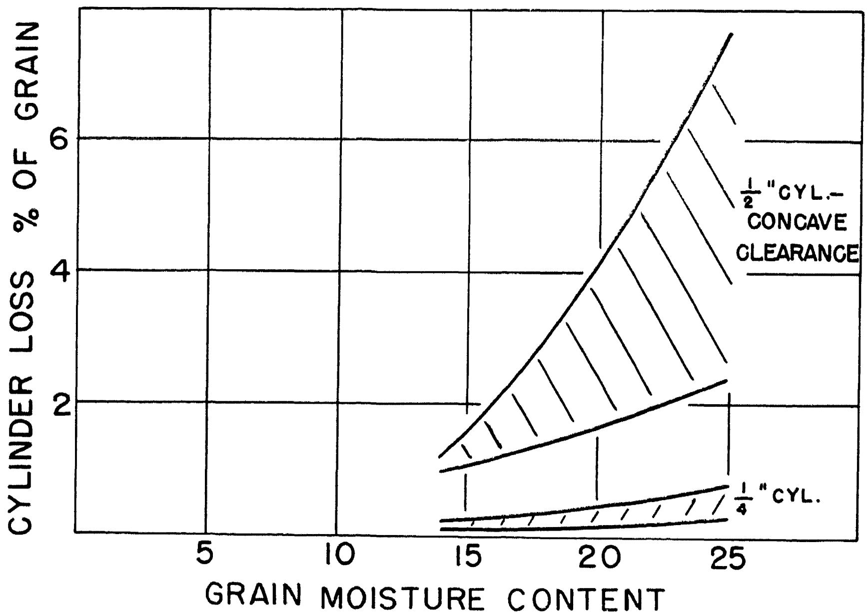

Figure 19

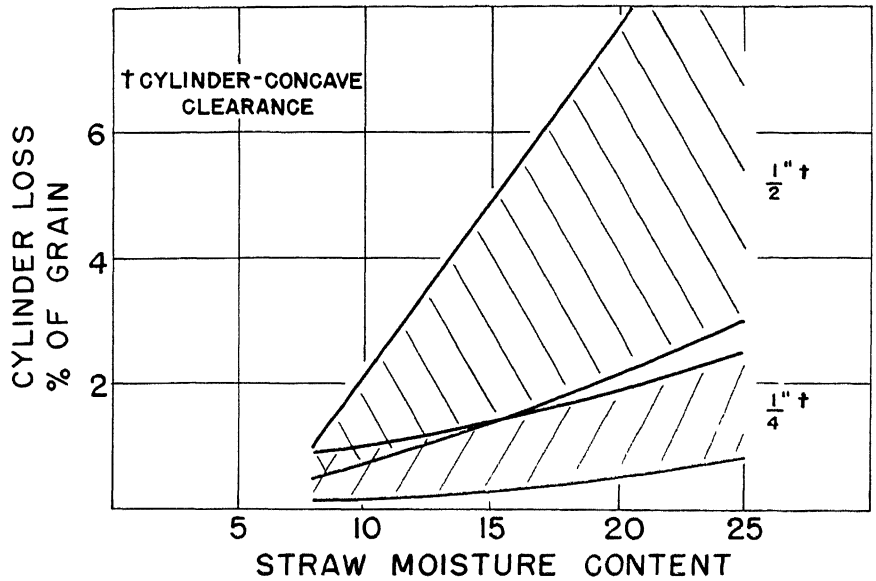

Figure 20

with a closer cylinder-concave clearance or a higher cylinder speed, the cylinder loss can be kept well below one percent. From this it seems that present combine cylinders have the capability of threshing high moisture grain. In this series of tests the cylinder speed was constant at 1400 RPM. Also, all the machines used had full width cylinders common in the pull type machines.

Rack Loss

Rack loss apparently increases at both extremes of the moisture range. See Figures 21, 22, and 23. In the low moisture range (below 13 percent straw moisture) this is undoubtedly due to overthreshing of

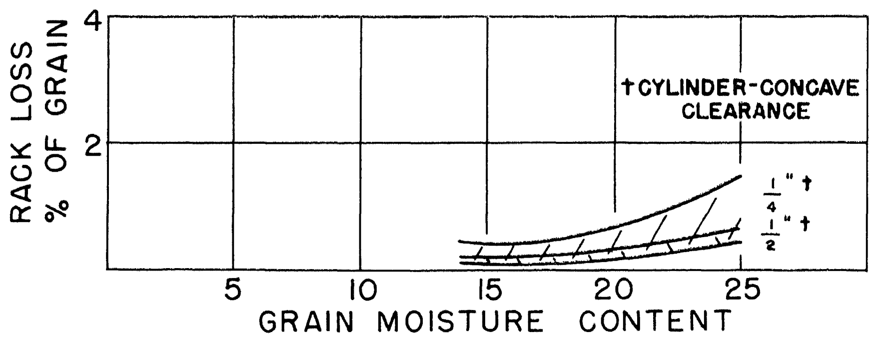

Figure 21

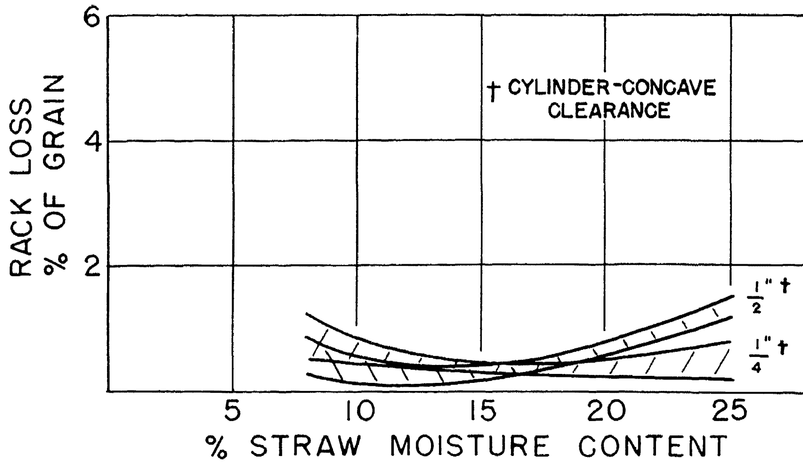

Figure 22

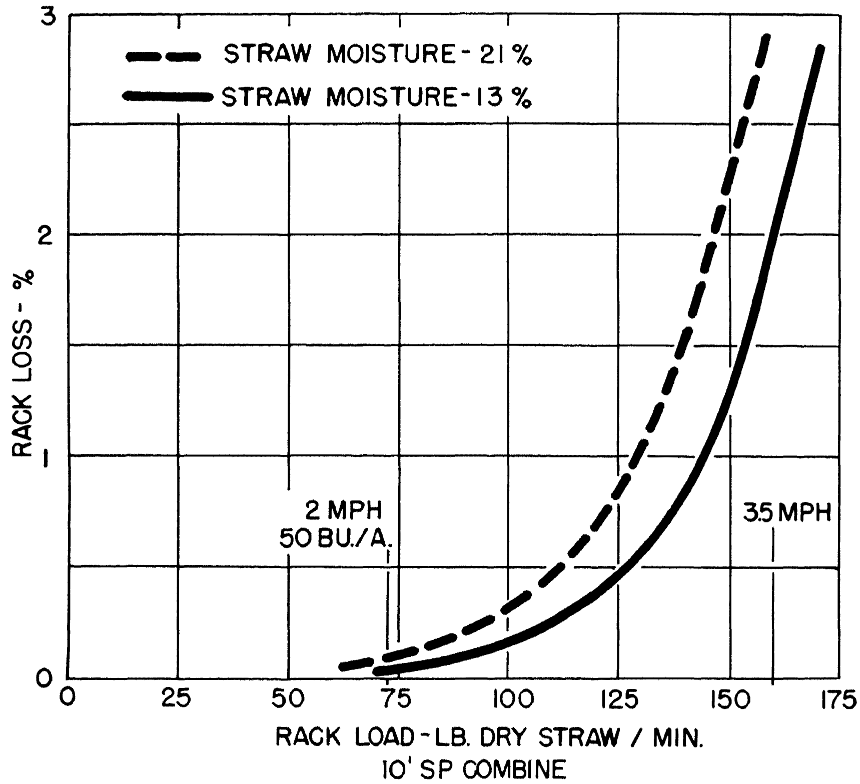

Figure 23

the straw, whereas at high moistures (above 19 percent straw moisture) threshing is less complete and kernel density is lower which retards rapid separation. It would appear that intermediate straw moistures (13-19 percent) would be quite desirable in minimizing loss.

It should be noted that during the re-wetting and drying period straw moistures will normally be below grain moistures, except in early morning or late evening. It is common to find straw moistures below 10 percent during the normal combine hours.

Shoe Loss

Shoe loss appears to increase as the moisture content decreases; although the exact relationship is difficult to determine because of the many adjustments possible for optimum shoe operation. See Figures 24 and 25. In a series of tests involving shoe adjustment there appeared to be no great difference in the optimum adjustment of the shoe in the moisture range of 16-20 percent as compared with normal combine moistures.

An increase in moisture content reduces shoe load significantly. This can be seen in Figure 26.

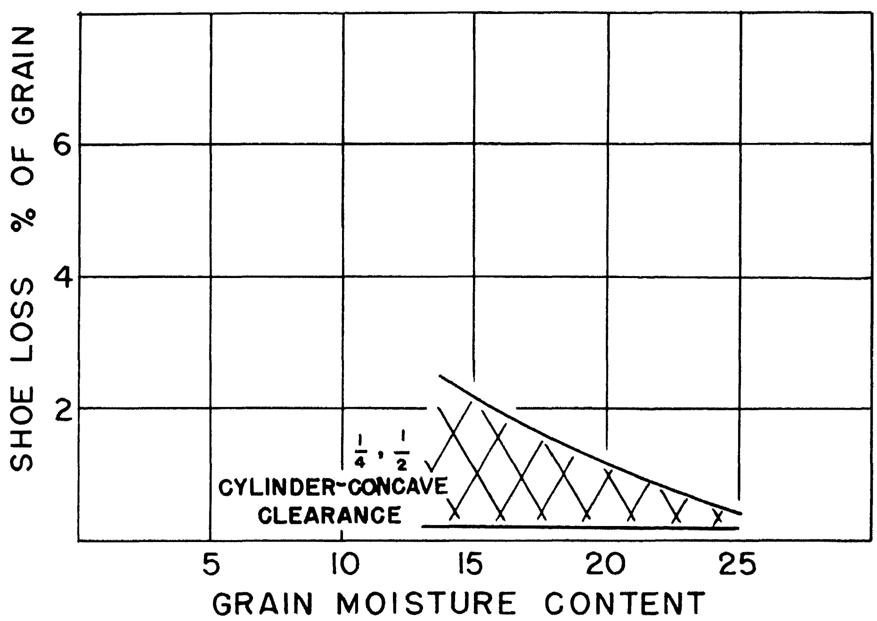

Figure 24

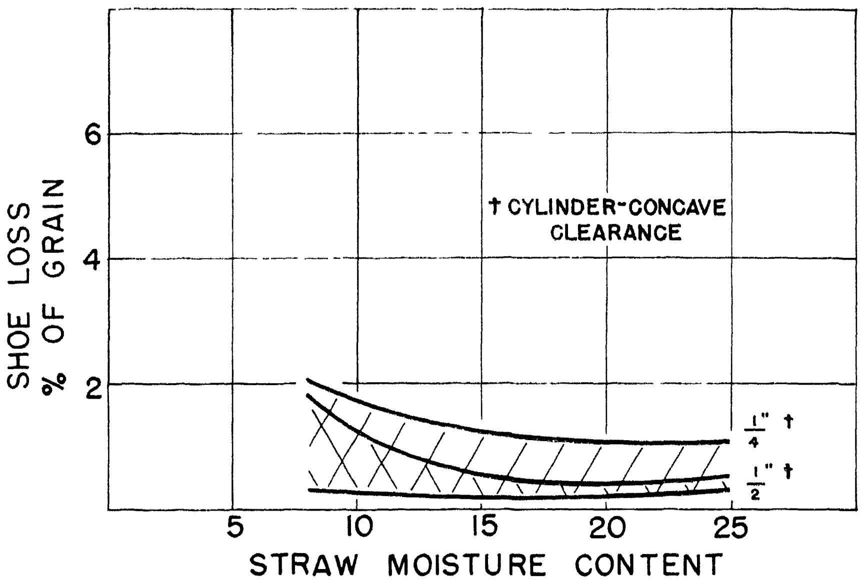

Figure 25

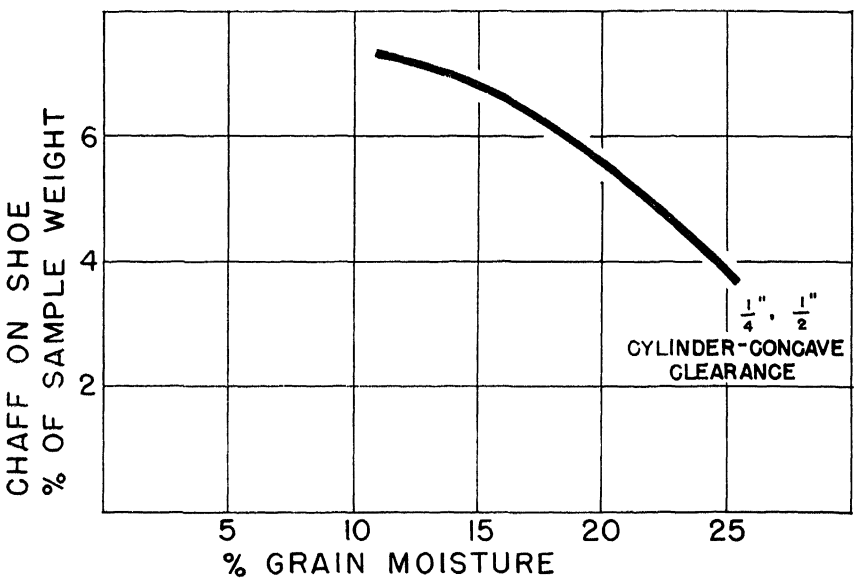

Figure 26

Total Machine Loss

From the standpoint of machine efficiency, when all machine losses are related to the crop condition, the optimum moisture conditions occurs at a moisture content higher than those associated with 14 percent grain. See Figures 27 and 28. These figures present a consolidation of cylinder, rack and shoe loss which represents those losses which can best be influenced through machine adjustment. These curves are largely influenced by cylinder loss. It should be noted that the lowest loss occurred between 15 and 20 percent at ¼ inch cylinder-concave clearance in the original drying period. In the re-wetting and drying period, the machine loss at ¼ inch cylinder-concave clearance at 15 percent straw moisture is nearly equivalent to ½ inch at 8 percent straw moisture. From this, equal machine efficiency can be obtained at higher moistures, with the chance of greatly reducing the cutterbar loss.

(C) METHOD EFFICIENCY

Cutterbar Loss

In many respects Figure 16 illustrates the most true relationship of cutterbar and shatter loss since both of these are influenced by time as well as moisture content. It is true, however, that many times the

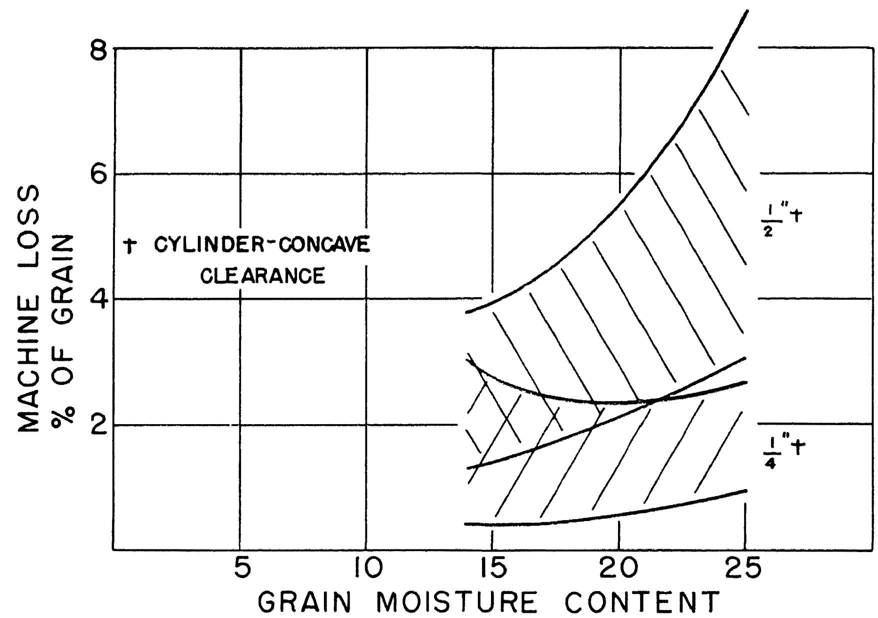

Figure 27

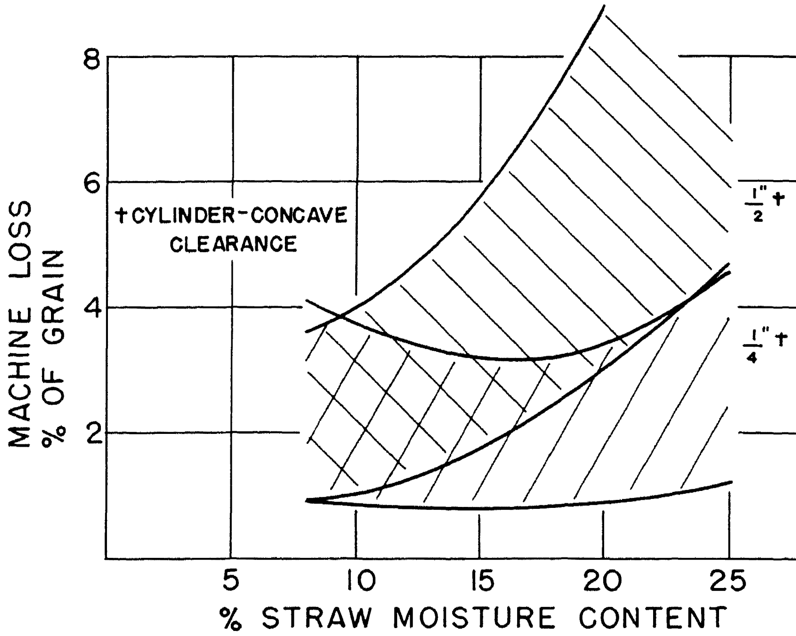

Figure 28

major loss experienced at the time of combining is cutterbar loss. For that reason it is desirable to see in a general sense the influence of moisture content on cutterbar loss. This is shown in Figure 29.

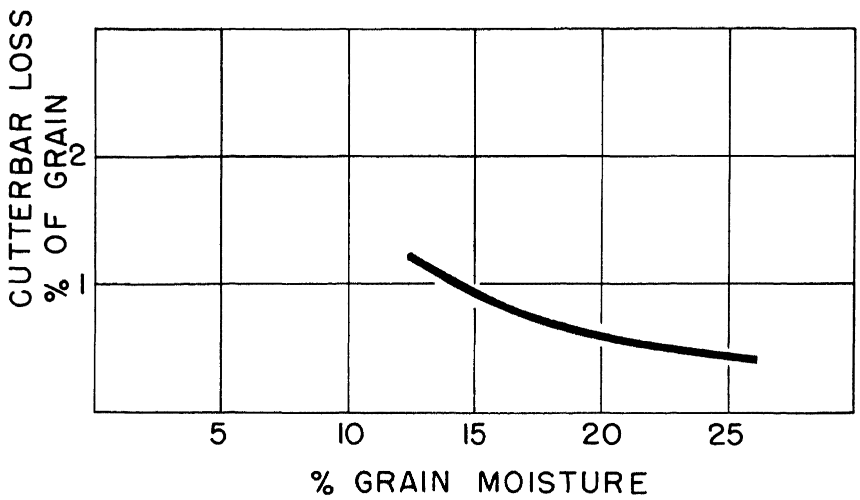

Figure 29

Total Loss

When shatter and cutterbar losses are added to the machine losses the most desirable stage of harvest is shifted toward higher moisture contents. See Figure 30. For the original drying period the highest method efficiency occurs from 17-22 percent grain moisture.

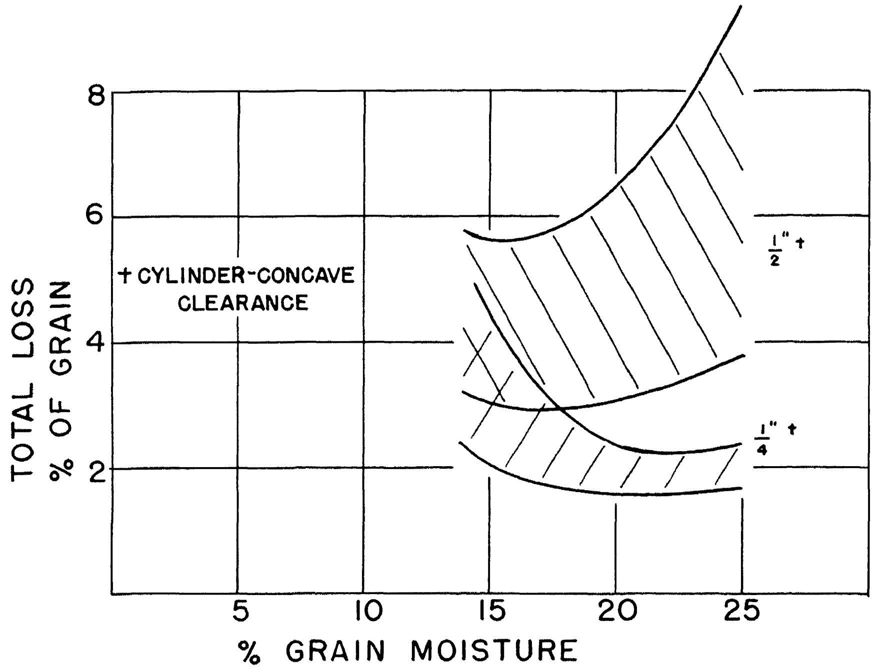

Figure 30

It is difficult to portray method efficiency for this re-wetting period of harvest. Cutterbar and shatter loss tend to increase as the harvest is delayed; therefore the loss experienced depends upon the extent to which harvest is delayed.

IX. COMBINE FUNCTIONING

Most of the combines used functioned well in grain below 20 percent moisture except where rain or dew was on the surfaces of the straw. High moisture chaff does not handle as well as dry material in the tailings system. Clogging resulted in machines that tended to excessively restrict tailings flow.

Power requirements of the combine were observed to be higher in high moisture grain, although no precise measurements were made. One auxiliary engine drive combine proved to be under-powered.

At no time was crackage or chaff content of the sample great enough to reduce the U. S. grade.

X. VARIATIONS IN THE METHOD OF HARVEST

Because of the relatively low moisture content suitable for direct combining, any method which would increase the rate of drying would seem advantageous. In this regard combining could occur earlier but at relatively low moisture contents. Windrowing was one method attempted.

The rate of drying is influenced somewhat through the use of the windrower; however at the 20 percent level there is only one day advantage. See Figure 31. The influence of the windrower was more evident when studying straw moistures. See Table 7.

TABLE 7.—Relationship of Windrower on Straw Moistures

Date	Moisture Content	
	Standing Straw	Windrowed Straw
June 30	54.6	54.3
July 1	48.9	22.4
July 2	43.2	21.6

The windrower is used at a time when the kernels shattered by the cutterbar is essentially nil; head loss accounted for about 18 pounds per acre. The combine pickup loss was in the order of 10 pounds per acre for about 18 percent moisture grain when the cylinder-type pick-up device was used. The total cutterbar loss would then be 28 pounds per acre assuming no dropped heads by the windrower were picked up by the combine pick-up. This is about the same loss as experienced with direct combining at 20 percent.

The cylinder pick-up loss was surprisingly low and the windrows remained up on the stubble well even though they were left in the field

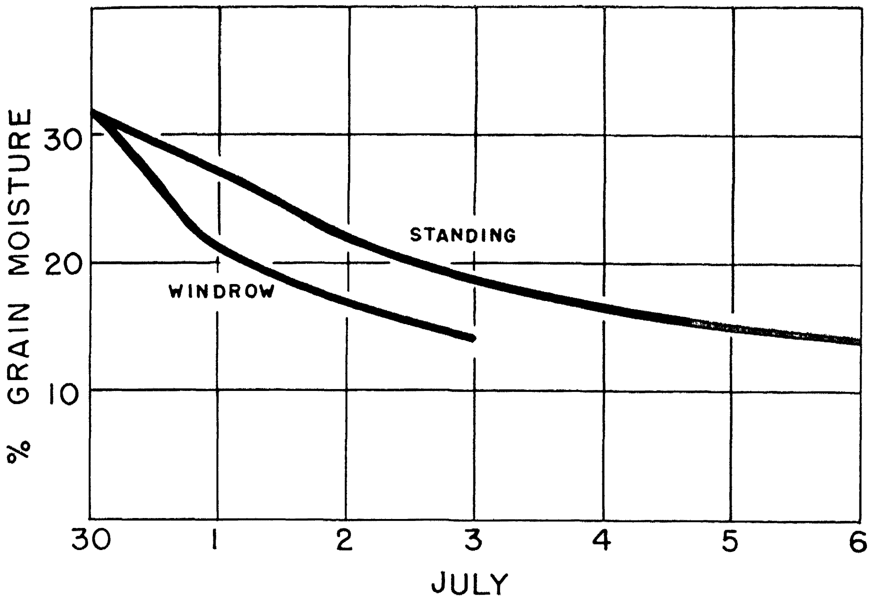

Figure 31

for extended periods. See Figure 32. Pick-up guards were tried, however, the header had to be run quite low thereby taking the stubble straw into the machine, also many heads were clipped off. These two characteristics made the process quite undesirable.

It was determined that as the windrow wets and dries the test weight reduction is greater than the standing grain. See Table 8.

In the replicated plots used to determine the harvested yield, the windrowed plots were lower by approximately four percent. This determination was made in 1956 when the windrows laid a minimum of five days during which time birds were observed to feed often on them.

TABLE 8.—Test Weights of Grain from the Windrow as Compared with Standing Grain Two Weeks After Windrowing

Date	Test Weight of Windrow	Test Weight of Standing Grain
July 12, 1955	55.4	58.4
July 26, 1956	55.2	56.5

Figure 32—Windrows remained up well on the stubble even after heavy rains.

In 1955, combining of the windrows was accomplished within 48 hours. A high test weight was observed from this grain windrowed at 30 percent grain moisture, threshed at 16.5 percent grain moisture. Grain from the windrow had a test weight of 60.9 pounds per bushel whereas standing grain direct combined on the same day tested 60.4 pounds per bushel. It would appear the quicker dry grain can be threshed the higher will be the weight per bushel.

From this, it would appear that windrowed grain should be threshed as soon as possible. In doing so, the harvest season can be shifted somewhat earlier and the grain and straw is likely in a moisture condition which is subject to less damage from the combine cylinder. It is quite doubtful if these advantages can be realized in enough seasons or are significant enough to justify windrowing as an additional operation.

The use of the mower-buncher did not form a satisfactory windrow. With additional development, this machine could be made to work, however.

One year a plot was cut with the binder and later threshed by feeding the sheaves into a combine. This treatment was not replicated; therefore, no great confidence can be placed on yield. It was indicated that the binder harvested yield was about 100 pounds below that which was combined direct. Total binder loss and losses around the shock was about 40 pounds per acre. The condition of the grain was excellent with a test weight of 58.9 pounds per bushel, 58.1 pounds per bushel being the best which resulted from direct combining.

XI. DRYING OF HIGH MOISTURE WHEAT

It was intended that the grain condition and quality dictate the optimum drying conditions; however, in many cases these factors were not materially altered in the drying process. For that reason, the characteristics of drying will be presented.

It should be noted that the potential condition and quality samples are used here as a basis for comparison of the grain resulting from any storage treatment. In this case, however, the immediately threshed samples were used since only the effect on the grain in drying was desired.

(A) EFFECT OF DRYING RATE ON TEST WEIGHT

In the two years that a variable rate of air flow was used in drying, the resulting influence on test weight has not been decisive. See Figure 33. For any one moisture content at the time of threshing the loss in test weight is inversely proportional to the air flow, no optimum being apparent.

The above data replotted makes the effect of drying temperature on test weight more apparent. See Figure 34. Results of Ramser's work is also presented here which corroborates the work done in these tests (9). Natural air is somewhat more desirable in maintaining test weight. The following discussion may provide some reasons for this fact.

The temperature of the air leaving the heated air bins was in the range of 75° and 85° respectively for the 100 and 150 degree air. Undoubtedly respiration of the kernel and mold growth was quite active at these temperatures. Respiration during drying would cause a dry matter loss and effect a lower test weight.

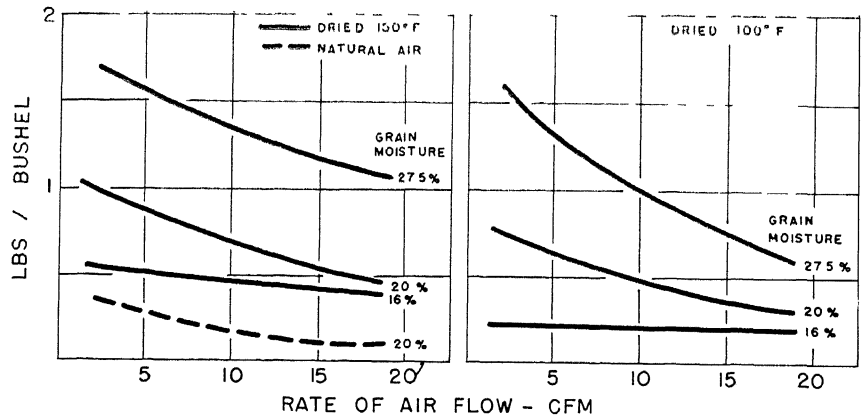

Figure 33

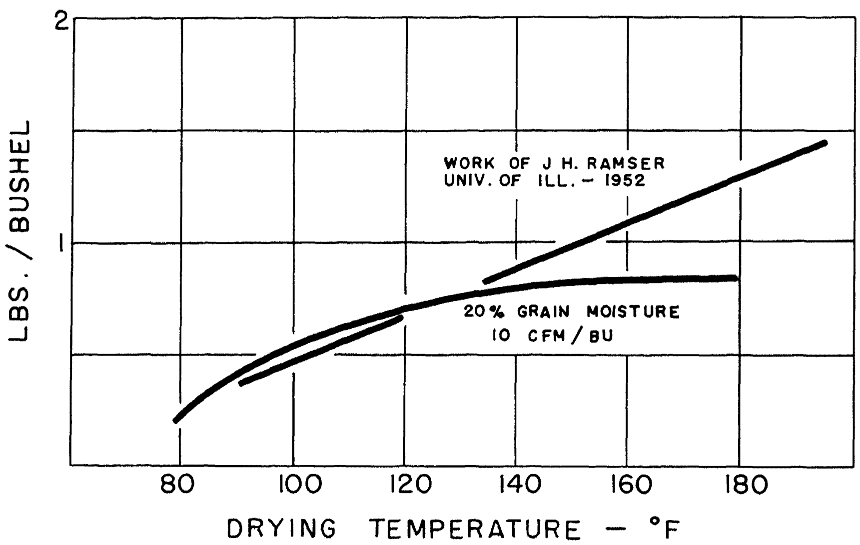

Figure 34

In checking if there was a reduction in dry matter for the heated air bins a statistical correlation between 1000 kernel weight and test weight was attempted. For those samples $r = .281$ with $r\ 5\% = .223$, which means there is correlation between these two factors and the loss of dry matter is verified. The extent of the dry matter loss seems to be much less than the test weight reduction.

(B) EFFECT OF DRYING RATE ON GERMINATION

Germination can also be considered to contribute toward the selection of proper air flows. It is assumed that the lower the germination the less stable the grain is in storage. Again the data are not decisive; however with low air flows at 27.5 percent moisture the germination was seriously reduced. See Figure 35. Even though 27.5 percent is well above the practical combine moisture content, a lower limit of 10 cfm per bushel would be required to preserve the germination. The data presented here is for 100° and 150° F. heated air. Adequate data are not available on natural air; however, from indications which are available natural air would be similar to heated air at 100° F. There was some indication that high air flows at 150° drying temperature failed to decrease the reduction in germination.

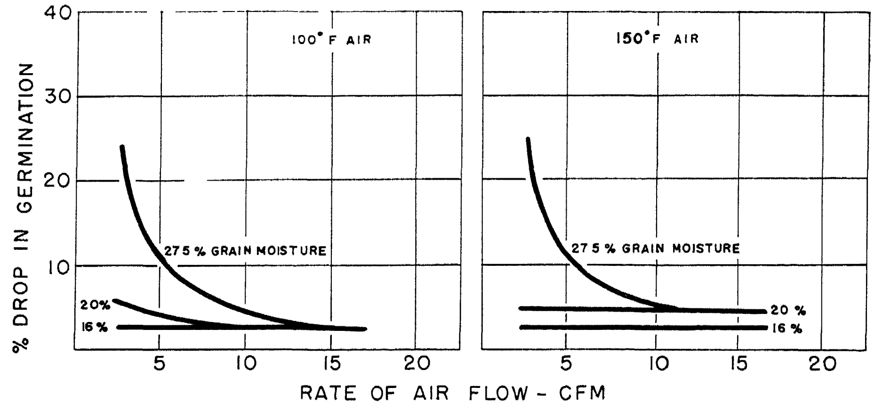

Figure 35

(C) EFFECT OF DRYING RATE ON MILLING AND BAKING

The tests which have been made were primarily to determine whether the reduction in test weight of the wet threshed grain had any effect on milling and baking. No difference was found. The wet threshed grain was equivalent to normal dry threshed grain when considering cookie diameter, flour yield, and mixogram area.

Ramser studied the effect of drying temperature of 20 percent harvested grain (9). No damage resulted to the milling and baking characteristics when the drying temperature was below 160° F.

(D) EFFECT OF DRYING RATE ON THE TIME REQUIRED

The driers used in this test were operated continuously 24 hours per day. Data are presented which allow the estimation of drying time given an initial moisture content, air flow and drying temperature. See Figure 36, 37, and 38. In working with these driers it was felt that wheat should be dry after one week of fan operation. Points of severe mold should be noted in these charts. Slight evidence of mold was observed on the top of the heated air bins receiving 4.5 cfm per bushel at 27.5 percent grain moisture.

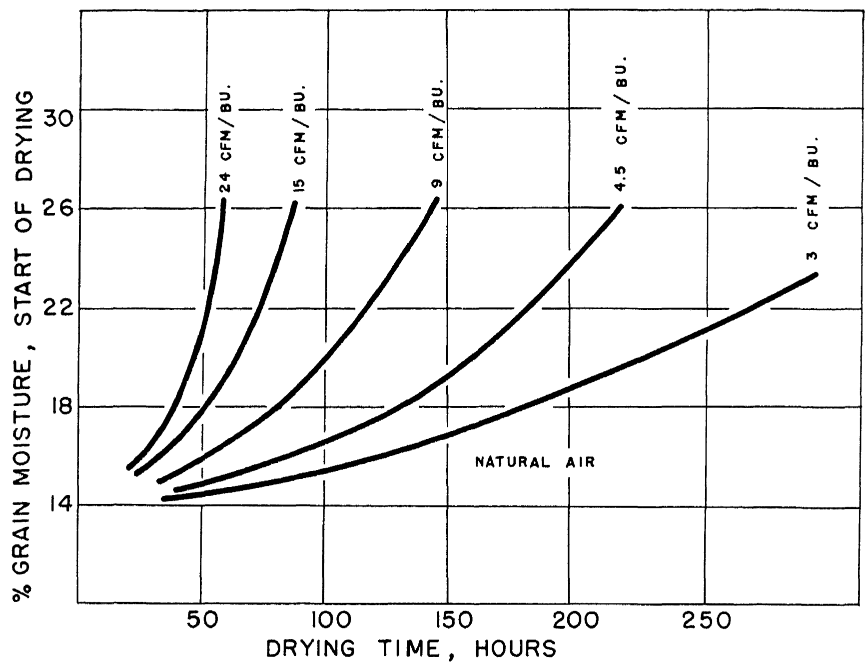

Figure 36

In studying the heated air drying time curves, the drying time for the lower air flows was longer than expected. See Figures 37 and 38. Assuming equal efficiency of moisture removal for all air flows, it would be expected that the drying time would be inversely proportional to air flow. Actually a lower efficiency of moisture removal is to be expected at high air flows which makes the extended drying time of additional significance. Apparently respiration was severe enough at low air flows to increase the quantity of moisture to be removed.

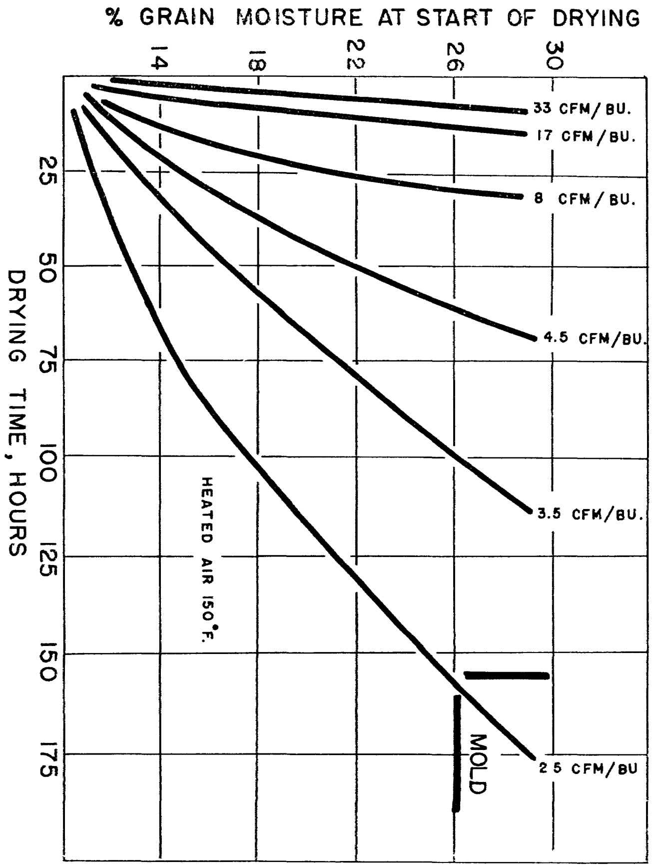

Figure 38

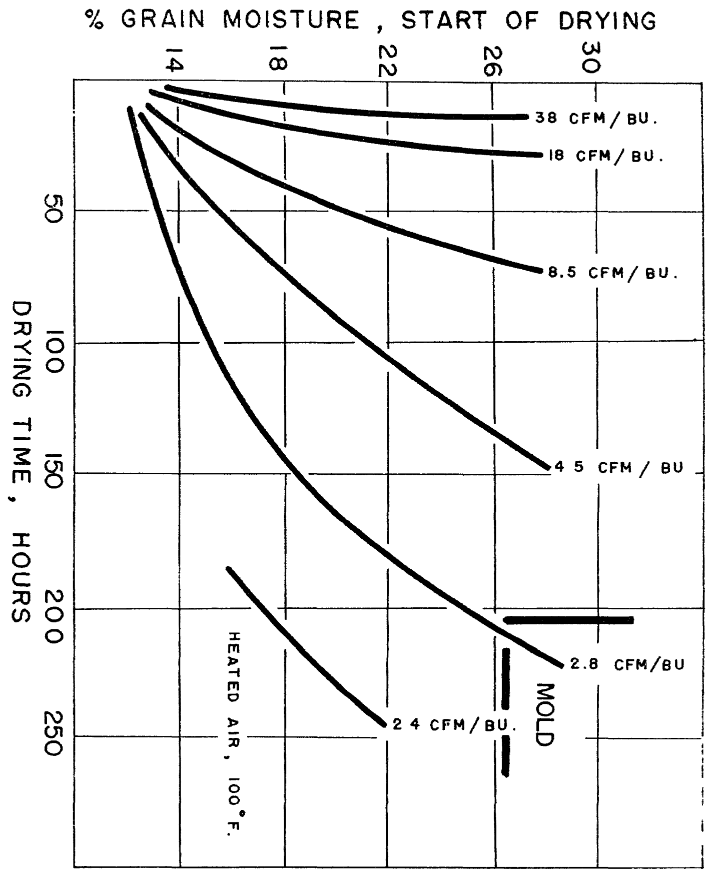

Figure 37

(E) SHRINKAGE

The volume of shrinkage may at times be of interest. See Figure 39.

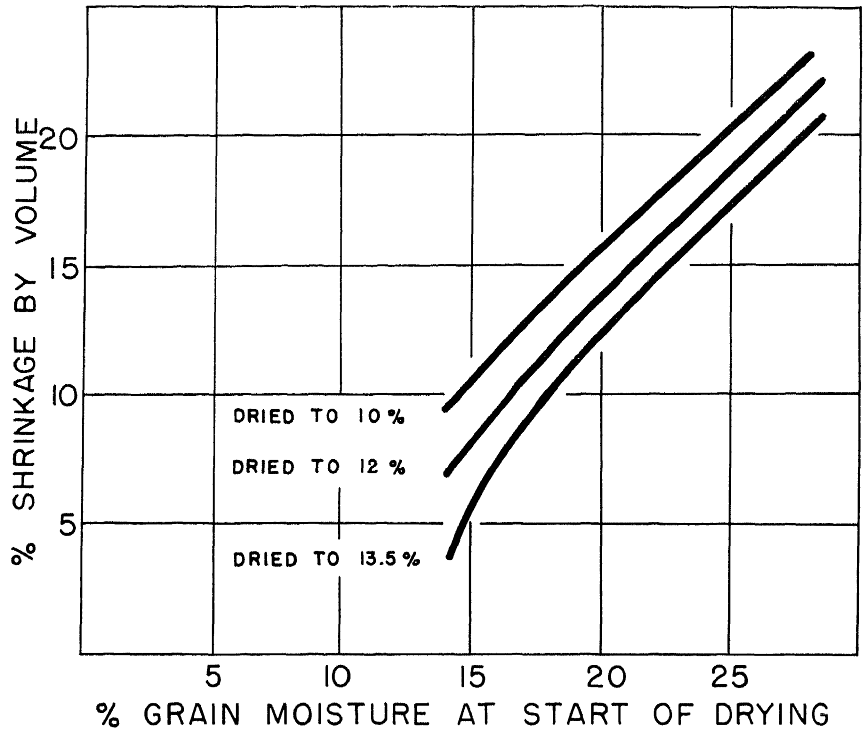

Figure 39

(F) EFFECT OF DRYING TEMPERATURE ON THE GRAIN MOISTURE END POINT

As indicated previously, the grain was removed from the drier when the top surface was at 14 percent. The end point of the entire bin for the various drying temperatures were as follow:

Heated air 150° F	-------	less than 10 percent
Heated air 100° F	-------	12 percent
Natural air	-------	13.5 percent

The fact that the final composite moisture content is difficult to control when using heated air is quite a disadvantage unless tempering to 14 percent moisture is accomplished before the sale of the wheat. No premium is paid for wheat below 14 percent. From Figure 40, 100 pounds of wheat at 14 percent moisture, weighs only 95.5 pounds at 10 percent. This is a loss to the producer.

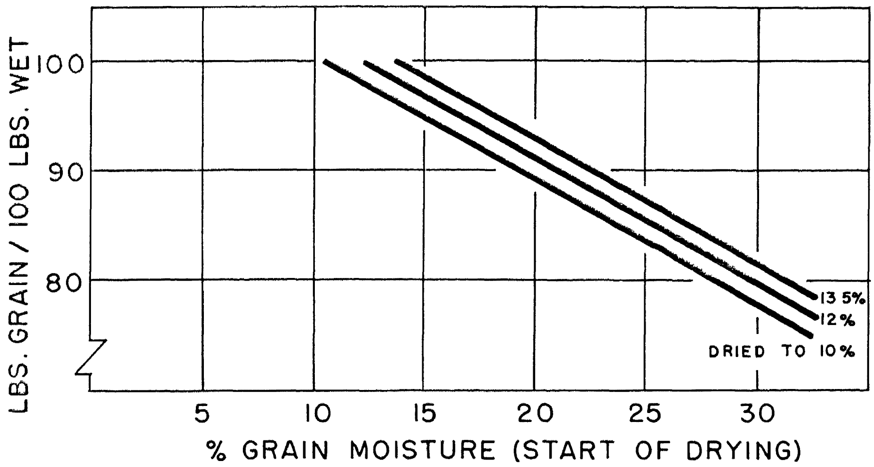

Figure 40

(G) GENERAL RECOMMENDATIONS

From the standpoint of preserving the grain condition, forced natural air drying seems most desirable for drying high moisture grain. Minimum air flows are difficult to establish from the data; however the following are suggested:

20 percent grain	5 cfm/bu
18 percent grain	3 cfm/bu
16 percent grain	2 cfm/bu

Static pressure required to obtain air flows above five cfm per bushel becomes quite extreme. Hall and Maddox have established this relationship (10). Many fans now being used for farm grain ventilation are capable of only four inches maximum static pressure.

XII. SUMMARY

The objective of this study was to preserve the condition and quality of Ohio grown wheat, and minimize the grain losses experienced by the harvesting method. Direct combining at high moisture, one attempt at accomplishing the objective, received major emphasis. Windrow harvest as well as the binder method was studied.

The overall rate of drying of the grain was 2.5 percent per day for Ohio conditions. There are normally four days between 20 and 14 percent.

As wheat stands in the field after maturity the following occur:

(1) Test weight in pounds per bushel decreases at the rate of about .23 pound per bushel per day.

(2) Germination reduces only slightly.

(3) Leaching and oxidation accounts for only about a 1.4 percent loss in dry matter in 20 days.

(4) There is no effect on milling and baking quality as long as the grain is handled well during and after harvest.

(5) When considering the combine method of harvest at various dates there is approximately 12 pounds per acre per day less grain that the combine can harvest due to shatter or related losses.

In regard to high moisture harvest the recommendation must be to limit combining to 20 percent grain moisture or below in order to maintain high test weight, germination and storability.

When considering combine efficiency the following seems to be true:

(1) Cylinder loss increases as the moisture content increases; however present combines have capability of threshing the grain.

(2) Rack loss seems lowest in an intermediate moisture range, 13 19 percent straw moisture.

(3) Shoe loss reduces as moisture content increases.

(4) The highest machine efficiency occurred between 15 and 20 percent grain moisture.

(5) It appears in terms of combine functioning that 20 percent grain moisture should also be the maximum.

Cutterbar and shatter losses are reduced by early season and high moisture harvest. Highest method efficiency was observed between 17 and 22 percent grain moisture during the original drying period of harvest.

Both from the standpoint of method and machine efficiency slightly higher than normal combine moistures are advantageous. Grain from such a method of harvest potentially has better condition if handled and stored well. It appears that in an average year the harvest might be completed as much as six days earlier. Assuming this can be done there will be approximately a bushel per acre more grain harvested which is available to defray the cost of drying. On an extreme year during the test period this value was three bushels.

When grain was windrowed in the 30-35 percent moisture range the drying rate was increased so that dry threshing could be accomplished sooner. Windrower cutterbar and combine pick-up losses were not found to be excessive but were in the same order as direct combining. Windrows which were left in the field for extended periods had a lower test weight of grain and combine yield as compared to standing grain. The windrows remained on top of the stubble. It is doubtful if the windrower proved to be much of an advantage in these tests.

In terms of test weight the binder method seemed superior.

Grain threshed between 14 and 20 percent must be dried. From the standpoint of preserving the highest test weight, and highest dry matter, natural air seems desirable for drying high moisture wheat. Minimum recommended air flows would be as follows:

20 percent grain	5 cfm/bu
18 percent grain	3 cfm/bu
16 percent grain	2 cfm/bu

Drying time using natural air would be approximately 150-180 hours for the above air flows.

Milling and baking characteristics of the grain are likely not to be damaged from drying temperatures up to 150° F.; however, test weights and at times germination have been reduced at this temperature. Air flows for heated air should be at least as high as natural air.

Characteristics of shrinkage, final moisture, drying time, and required static pressures have been proposed.

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